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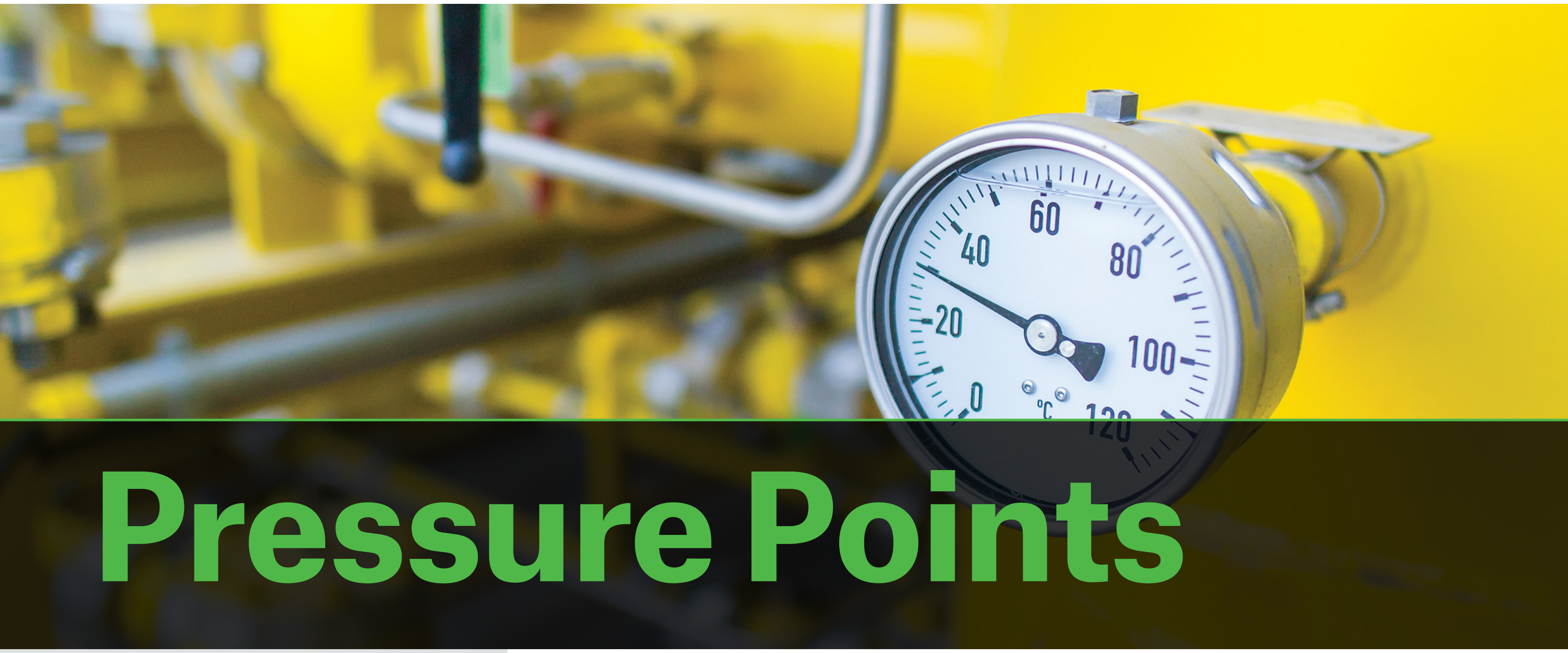

Pressure Points

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HSB, a Munich Re company, is a technology-driven company built on a foundation of specialty insurance, engineering, and technology, all working together to drive innovation in a modern world.

What's All the Buzz About Hydrogen!

Authors: Thomas Pastor, Vice President, Codes & Standards, HSB Global Inspection & Engineering Services and Dan Peters, Associate, Pressure Vessels and Piping, Structural Integrity Associates, Inc. (SIA)

Anyone who is following climate change issues and the expansion of the use of renewable energy would have seen the subject hydrogen popping up all over the place. Just do a Google search using the following words "hydrogen renewable energy climate change" and dozens of links will be displayed promoting the use of green or renewable hydrogen, made from the electrolysis of water powered by solar or wind, as indispensable in achieving climate neutrality.

According to the U.S. Department of Energy (2020), hydrogen energy storage (HES) offers unique benefits beyond the potential for long-term, seasonal energy storage as stated in the Energy Storage Grand Challenge Roadmap. Examples include grid leveling and stabilization services and coupling with intermittent renewable energy sources to enable reliable, emission-free electricity. On the right is a graphic highlighting how hydrogen can play a central role in both bidirectional and one-way energy storage.

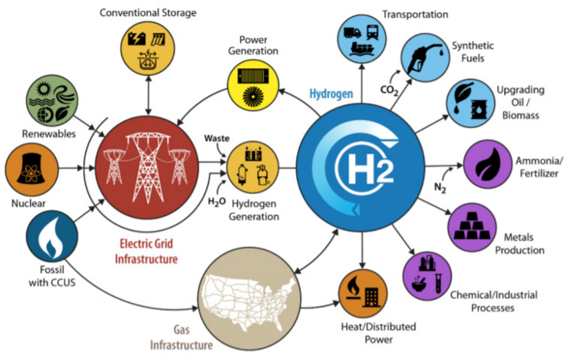

Figure 16. The H2@Scale vision: hydrogen can play a central role in both bidirectional and one-way energy storage[145]

Ref: DOE Energy Storage Grand Challenge Roadmap

A recent news story reported:

- *Hydrogen initiatives are accelerating globally.*
- *200+ large-scale projects have been announced across the value chain, with a total value exceeding $300 billion*
- *30+ countries have national hydrogen strategies in place, and public funding is growing*

Traditionally, hydrogen is produced in a steam-methane reforming process where methane reacts with steam under 45-375 psi (3-25 bar) pressure in the presence of a catalyst to produce hydrogen, carbon monoxide, and a relatively small amount of carbon dioxide. Hydrogen produced in this manner is often referred to as 'gray hydrogen' since it relies on the use of a fossil fuel and produces carbon dioxide as a byproduct. But with the expansion of low-cost renewable energy, the majority of the large hydrogen production projects underway around the world are making hydrogen via electrolysis. Hydrogen produced in this manner is referred to as 'green hydrogen'. Here is a short list of hydrogen projects underway around the world as reported in the news:

1. HyDeal Ambition (67GW)
   - Location: Multiple sites across Western Europe, starting in Spain in southwest France, and then extending to eastern France and Germany.
   - H_2 output: 3.6 million tonnes per year
2. Asian Renewable Energy Hub (15GW)
   - Location: Pilbara, Western Australia
   - Planned use of H_2: Green hydrogen and green ammonia for export to Asia.
3. AquaVentus (10GW)
   - Location: Heligoland, Germany
   - Power Source: Offshore Wind
   - H_2 output: one million tonnes per year
4. Helios Green Fuels Project (4GW)
   - Location: Neom, a planned city in the northwest Saudi Arabia
   - Power source: Onshore wind and solar
   - Planned Use of Hydrogen: to produce green ammonia, which would be transported around the world and converted back into H_2 for use as a transport fuel.

On a mass basis, hydrogen has nearly three times the energy content of gasoline [120 MJ/kg for hydrogen versus 44 MJ/kg for gasoline]. But there are challenges storing and transporting hydrogen. The low volumetric density of hydrogen makes it quite expensive to store and transport it in gas or liquid forms. [To exist as a liquid, H_2 must be cooled below its critical point of 33K (-240°C, -400°F)] Alternatively, to store hydrogen as a gas economically, it typically needs to be compressed between 350-700 bar (5,000 - 10,000 psi). Either of these methods is energy intensive and costly. One option that has also received a lot of attention is converting hydrogen to ammonia using a process called the Haber-Bosch process. Ammonia has several desirable characteristics that suggest its use as a medium to store hydrogen. It can be liquefied under mild conditions (Thomas and Parks, 2006). The vapor pressure of ammonia at room temperature is 9.2 bar (121 psi G). Its physical properties are similar to those of propane, meaning that it can be stored in a simple, inexpensive pressure vessel. Ammonia also has a large weight fraction of hydrogen; hydrogen makes up approximately 17.6% of the mass of ammonia. When these two factors are combined, the result is a liquid that is simply contained, with a volumetric hydrogen density about 45% higher than that of liquid hydrogen. This is why many companies are looking at the option of producing hydrogen using excess renewable energy and then converting it to ammonia. The ammonia is then transported around the world, where at its final destination would once again be converted back to hydrogen for use in power generation, transportation, and even residential cooking and heating.

Based on the information presented above, it comes as no surprise that HSB and SIA have been receiving numerous inquiries about constructing pressure vessels for production and storage of hydrogen and ammonia. Some of you may be old enough to remember the talk about the developing hydrogen economy in the early 2000's. During that timeframe ASME committees carried out much work to develop rules within its standards for the generation, storage, and transport of hydrogen. Today rules exist for the construction of pressure vessels and piping within Section VIII and B31.12 to be used in the production and transport of hydrogen. Let's take a closer look at the rules within the ASME standards, and some of the manufacturing challenges.

ASME Standards and Hydrogen

Infrastructure equipment made to store and handle hydrogen during its production, distribution and use is critical to the successful implementation of hydrogen as an energy storage medium. ASME has had standards used in the design and manufacture of hydrogen vessels for many years. In recent years, ASME has focused on standards related to the hydrogen.

There are many different designs used in the construction of vessels for hydrogen storage and transportation. A common design uses ASME Section VIII, Divisions 2 and 3 (VIII-2 & VIII-3) for a seamless pipe with the ends hot formed to a hemispherical dome on each end made of low alloys steels. Similar cylinders have a composite wrapped steel liner leveraging VIII-3 and Section X as Composite Reinforced Pressure Vessels (CRPV's). There are also ASME Section X cylinders which are composites with stainless-steel end bosses for connections on each end.

ASME Section VIII, Division 1 (VIII-1) is the most used standard for the design and construction of pressure vessels around the world. The scope of VIII-1 is for vessels with pressures generally not exceeding 3000 psi (20 MPa) and is common for low pressure storage vessels. VIII-1 has the largest design margin (3.5) and typically uses lower strength steels, known for higher ductility. ASME developed VIII-2 in the late 1960's. Today, it has two classes of vessels with a design margin of 3.0 and 2.4. ASME VIII-3 has been published since 1997 and is generally for pressure vessels over 10 ksi (70 MPa) with the lowest design margin of 1.8.

Many applications in the hydrogen economy, however, are requiring higher pressures to make transport of the gas more economical (Office of Energy Efficiency & Renewable Energy, 2016). Due to its low energy volume, most cars are operating with a high-pressure tank (vessel) of 10,000 psi (69 MPa) containing 5 kg of compressed hydrogen. These cars are typically filled at stations with storage vessels that are 15,000 psi (103 MPa).

ASME VIII-2 has many higher strength materials allowing lighter weight and more economical vessels. However, fatigue becomes a more prevalent issue due to the higher stresses. Evaluation of the life of the vessels in key critical areas and establishment of an in-service inspection program is critical to long term safe operation. VIII-2 includes a fatigue assessment methodology for most materials permitted for construction but leaves addressing the hydrogen environment up to the designer.

ASME acknowledges that it does not cover many cases of environmental effects such as hydrogen. ASME Section II-D, Nonmandatory Appendix A A-702 contains general information regarding hydrogen damage, embrittlement, blistering, and cracking. However, little specific guidance is provided to the designers of hydrogen equipment.

ASME formed a special "Project Team on Hydrogen Tanks" to develop rules for design in hydrogen environments in the early 2000's. The committee consisted of industry representatives and worldwide researchers involved in high-pressure hydrogen infrastructure. The rules first appeared in 2007 in ASME VIII-3 in KD-10 "Special Design Requirements for Vessels in High Pressure Gaseous Hydrogen Transport and Storage Service".

KD-10 captured the industry experience along with recommendations for testing for hydrogen service. This included criteria such as the relevance of the hydrogen partial pressure of hydrogen 6,000 psi (seamless) and 2,500 psi (welded). KD-10 mandated evaluation of fatigue cracking using fracture mechanics and required Manufacturer's to test materials for fatigue crack growth rate (da/dN) and the threshold for hydrogen assisted cracking (KIH). Fatigue crack growth rate and KIH testing has since been completed by laboratories worldwide, including Sandia National Lab, Savanah River National Lab, NIST, and Japan Steel Works on two common industry materials (SA-372 and SA-723) used for storage vessel construction. Code Case 2938 was first published in early 2019 to eliminate the need for Manufacturers to perform redundant testing to comply with KD-10. This testing showed significant increase in crack growth rate and limitations of critical crack size compared to the materials used in an inert environment.

Other standards for supporting hydrogen storage tanks include ASME Section X that contains requirements for fiber-reinforced thermosetting plastic pressure vessels. This standard is used both for cylinders of fully composite materials and the CRPV's which are manufactured to VIII-3 and ASME Section X Appendix 8 (Class III).

Hydrogen storage also relies on piping and piping components for connection of the vessels to storage vehicles, etc. ASME B31.12 (2008) responded to the need for piping and piping components in the hydrogen market. This standard references other B31 standards to incorporate "best practices", such as B31.3, Process Piping; B31.1,Power Piping; B31.8, Gas Transmission and Distribution Piping Systems; B31.8S, Managing System Integrity of Gas Pipelines; and VIII-3.

An additional challenge for many operators will be the life management. The fracture mechanics design approach of ASME VIII-3 or even the fatigue based approach of an ASME VIII-2 vessel will result in a vessel with a finite life. Some equipment was installed less than ten years ago is already exceeding the design life. Requalification of vessels in fatigue service is not new. ASME PCC-3, Inspection Planning Using Risk Based Methods, contains methodology for requalifying vessels in cyclic service that has been in use for decades. The method allows for continued use of the vessels beyond the design basis with a proper program of asset management, maintenance of the design basis documents, tracking of in-service cyclic usage, and periodic inspection for plausible failure modes. And of course, consideration of jurisdictional requirements should not be overlooked.

Unfortunately for many end-users, it is not uncommon to develop an in-service inspection program to be considered during design or installation. Even simple seamless cylinders are often mounted in racks making disassembly of the system necessary to access even the OD of the cylinders.

Methods for evaluation of many of the hydrogen damage modes, if found, are contained in API 579-1 / ASME FFS-1, Fitness for Service Standard. Many of these damage assessment procedures can be implemented, including evaluation of the continued life of the vessel using fracture mechanics. However, consideration of the effects of hydrogen embrittlement from KD-10 and Code Case 2938 should be considered.

There have been several case studies recently regarding the use of the methods in the ASME standards for life assessment in hydrogen environments, particularly with Code Case 2938. Discussions at the ASME Pressure Vessels and Piping (PVP) conference, as well as with the study group has led to additional study about lower pressure hydrogen and the effect on fatigue life. This will be published at the upcoming ASME PVP 2021 Conference and will show that even at pressures as low as 1 bar of hydrogen, there can be substantial detrimental effect on the life of hydrogen equipment (Ronevich and San Marchi, 2021). This could have significant future ramifications in all parts of ASME's hydrogen codes and standards, including ASME VIII-1 or other low pressure vessels.

Summary

The need to dramatically reduce CO_2 emissions and meet global warming goals will drive market changes that will impact all our lives for decades to come. In the last 10 years, we have seen exponential growth in renewable energy in the form of solar and wind, with decreasing costs as mass production efficiencies are achieved. As stated earlier, many countries are betting on hydrogen to be one of the key components in achieving our environmental goals. All of this will drive the demand for pressure equipment to be used in the production, storage, and transmission of energy storage media such as hydrogen and ammonia.

ASME continues to evolve and advance its standards to keep pace with technology and the research supporting it. Many industries in the past have gone through similar evolutions to ensure that the equipment and personnel using it are able to function safely and design for the unknowns. A key aspect of the long-term success of the hydrogen economy will be not only in design, but in successful safe operation of the equipment over time in a cost effective manner. ASME will continue to develop standards for supporting the entire life-cycle of hydrogen equipment.

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Clarifications to Section V, Article 1, Mandatory Appendix III in the 2021 Edition

Author: Alex Garbolevsky

What revisions can we expect to see in the 2021 ASME BPV Code regarding Section V, Article 1, Mandatory Appendix III – *"Exceptions and Additional Requirements for Use of ASNT SNT-TC-1A 2016 Edition"*?

First, a bit of recent history. ASME BPV Code Section V, Article 1, Mandatory Appendix III was introduced via a revision to T-120(e) in the 2019 ASME Code edition. Its purpose was essentially three-fold:

1. replace previous references to the 2006 edition of ASNT SNT-TC-1A with the 2016 edition;
2. provide modifications to establish it as an NDE best practice, and;
3. make this best practice available to other ASME Code Sections and other standards for use by reference.

Since its introduction, about 30 interpretation requests have been handled through the Section V Standards Committee, which reflects some measure of difficulty that Code users had with its initial rollout.

Some of the apparent shortcomings of the 2019 Edition include the following:

– In contrast to other Section V Appendices, Mandatory Appendix III has a full-page layout similar to the SNT-TC-1A document. It doesn't follow the usual Roman numeral prefix-numbering scheme which makes it somewhat clumsy to reference the text.

– Unlike most ASME material specifications found in Section II, ASME does not have permission from ASNT to include SNT-TC-1A (2016) verbatim within the Code; therefore, a copy of the Recommended Practice is still needed to follow along and correlate the modifications in the Appendix.

– Mandatory Appendix III is silent when it does not modify a particular portion of the SNT-TC-1A document, some readers may consider unmentioned portions of SNT-TC-1A do not apply and may skip over them.

– A confusing dual-numbering system is used. "8.6" is the paragraph number for the 2019 version of the Appendix but "Paragraph 8.1.5" is the SNT-TC-1A (2016) paragraph number which it modifies. Appendix III then jumps to "Paragraph 8.2.1". For some, it was not clear how to treat SNT-TC-1A (2016) paragraphs 8.1.6, 8.1.7 and 8.1.8.

– The terms "Demonstration Examination" and "Practical Examination" for Level III Examiners were introduced without explanation. They are not defined in SNT-TC-1A or Section V. Also, SNT-TC-1A (2016) and Mandatory Appendix III both require the Written Practice to "identify the NDE techniques within each method applicable to the written practice." The definition of "technique" was not clear and is currently being considered in the Section V Standards Committee.

– SNT-TC-1A (2016) includes a requirement that a Level I & II Practical Examination should contain checkpoints that if not successfully completed would result in the failure of the examination. These checkpoints are commonly referred to as "kill points". Mandatory Appendix III mentions 10 different checkpoints but is silent on "kill points". Does this mean the "kill point" concept does not apply?

– The maximum recertification interval for Level I & II Examiners was reduced, without explanation, from 5 years to 3 years.

– Current Mandatory Appendix III appears to be silent on the extent of reexamination required for recertification. Must **all** examinations be retaken? A few? Only portions of exams?

- For those who have undergone ASME Certification audits or renewals using the 2019 Code, it was apparent that not all Team Leaders had the same interpretation of the Appendix's requirements.

So, to respond to the question, Section V 2021 Edition addresses these shortcomings and provides additional clarification as detailed below:

- A copyright NOTE was added near the beginning of the Appendix to state that paragraphs in the Appendix are adapted from ASNT SNT-TC-1A-2016, with 2018 Addendum and reprinted with permission of ASNT.

- Although it will still have a full-page format, paragraph headers will begin with Roman numeral "III" to identify the Appendix and will be captioned to provide a subject of the text.

- Each Appendix III subparagraph will be also be sequentially numbered and contain a captioned topic directly as indicated in SNT-TC-1A (2016). For example, numbered subparagraph III-112.2 will have the caption "Definitions".

- Additional numbering will be traceable directly to an applicable SNT-TC-1A (2016) paragraph, where one exists.

- If a paragraph or subparagraph from SNT-TC-1A (2016) is modified by Mandatory Appendix III in **any** way, the word *"paragraph"* and the paragraph number will be shown in *italic* font.

- Although they cannot be inserted verbatim, unchanged portions of SNT-TC-1A (2006) will be so noted with the word "unchanged" for easy cross-reference. The word "paragraph" and the paragraph numbers will be shown in normal font to indicate no modifications to the original text. This will make it less likely to miss any unchanged text in SNT-TC-1A (2016).

- Level III Demonstration and Practical Examinations are now defined in the 2021 Edition. The definitions are based on those found in ANSI/ASNT CP-189 and ASME Section XI Rules for Inservice Inspection of Nuclear Power Plant Components. Although the terminology may still be a bit confusing, the Level III "Demonstration" Examination is essentially a "Level II Practical" Examination for each NDE method and technique sought for certification. The Level III "Practical" Examination shall be completed by writing a Code compliant NDE procedure for each NDE Method sought for certification, as determined by the NDE Level III.

- Mandatory Appendix III (2021) goes on to explain that a "practicing" Level III may or may not need to write a procedure as part of a "Practical" certification exam but would be expected to do a "Demonstration Exam". A Level III performing purely administrative functions might even be able to skip both Exams. The specifics need to be defined in the Written Practice.

- "Kill points" will be mandatory for the Level I & II Practical Exams. Where appropriate, detection rates and the acceptable number of false calls **shall** also be addressed. These were added to SNT-TC-1A when it was revised in 2016.

- The maximum recertification interval for Level I & II Examiners will be restored to 5 years. The Level III maximum recertification interval will remain at 5 years by reference to SNT-TC-1A (2016), paragraph 12.2 which states: ***The recommended maximum recertification intervals are 5 years for all certification levels.***

- The extent of reexamination required for recertification will be at the discretion of the Level III Examiner. [SNT-TC-1A (2016)] "Paragraph 8.2" is excluded to prevent the "visual acuity examination" from being used as the sole "examination" for recertification purposes.

The Section V Standards Committee will review 2020 and later SNT-TC-1A Editions. Those reviews will form the basis for revisions to Mandatory Appendix III in subsequent Editions of Section V.

In summary, here are some key takeaways for the 2021 Edition of ASME BPV Section V:

- It will still be necessary to have a copy of SNT-TC-1A (2016) available when using Article 1, Mandatory Appendix III.

– Reformatting and call out of "unchanged" paragraph numbers in SNT-TC-1A (2016) should make Mandatory Appendix III easier to follow.

– Addition of previously "unmentioned" SNT-TC-1A (2016) subparagraphs should make them less likely to be overlooked when using Mandatory Appendix III.

– Revisions should make it easier for AIs, Certificate Holders and Team Leaders to better understand and work with the document leading to fewer Interpretation requests.

Keep in mind it is still the prerogative of the referencing Code or standard to choose to implement Section V, Article 1, Mandatory Appendix III. For example, the 2021 Edition of ASME BPV Code Section VIII, Divisions 1, 2 and 3 will continue to invoke Mandatory Appendix III, whereas Section I will maintain its reference to SNT-TC-1A (2006) without modification.

Ask the Engineer

Question: What is DOT RIN?

Answer: RIN is the DOT acronym for Retesting / Requalification of DOT or Transport Canada Marked Cylinders. Contained within the U.S Code of Federal Regulations DOT, cylinder regulations are found in the 49 CFR. This regulatory document contains the rules for new construction of DOT Specification Cylinders, Retesting / Requalification and several other items that relate to transportation cylinders, vessels, and containers. Each cylinder specification requires requalification within a recognized schedule found in 49 CFR Part 180.209, Table 1. The cycles of requalification of specific cylinders range from every 3 to every 20 years. Obviously if there is damage to the cylinder noted at any time during normal activities the cylinder should be removed from service and retested / requalified for the safety of all. Imagine a fire in an apartment complex where one of the fire extinguishers is damaged and has gone unnoticed? This is not the time to find a non-operable cylinder!

Question: What does HSB have to do with RIN?

Answer: The Hartford Steam Boiler Inspection and Insurance Company maintains an Independent Inspection Agency (IIA) Approval with the U.S. DOT. Contained within our approved scope of activities, HSB is allowed to perform an auditing function for organizations that maintain a DOT RIN Approval. RIN Approval holders carry out the 49 CFR Part 180 Regulatory Requirements for Retesting / Requalification of Cylinders, UN Receptacles, UN Portable Tanks, Multiple Element Gas Containers (MEGC), and DOT Specification Cargo Tanks.

Question: What exactly is HSB's scope regarding DOT RIN?

Answer: For companies looking to obtain their first DOT RIN Approval, HSB will assist them to establish a DOT Cylinder Retesting / Requalification system that is in compliance with the 49 CFR Part 180 Regulatory Requirements. The company is given 2-3 weeks to implement this new RIN Quality System, train their personnel, etcetera. Once the company feels they are ready, they will request HSB to schedule their IIA Pre-Survey (audit).

– HSB will create a Pre-Survey (Audit) Checklist based on the 49 CFR Part 180 Regulations and the customer's Quality System. The Quality System contains their Quality Control Manual and/or QC Procedures that describe how they will comply and carry out DOT Cylinder Requalification (RIN) activities at their respective locations.

– HSB then conducts the Pre-Survey (audit) at the customer location.

– If there are no deficiencies identified HSB will send a Pre-Survey Report letter to the customer and issue them a IIA Recommendation Letter. The IIA Recommendation Letter is the key IIA document for the customer. Any RIN application package sent into the DOT without a IIA Recommendation letter will be rejected.

– If deficiencies are identified by HSB during the Pre-Survey, the above process is repeated with the exception of providing the IIA Recommendation Letter to the customer. All deficiencies identified shall be verified as closed out prior to the issuance of the IIA Recommendation letter.

Question: What about a customer seeking the renewal of a DOT RIN Approval?

Answer: The process is identical to what has been described above for a new applicant with one exception. As the RIN Approval has an expiration date of five years from issuance, there should be five years of DOT RIN Retesting / Requalification records available for the IIA to review towards compliance with 49 CFR Part 180. HSB as the IIA will conduct this verification for all RIN Renewal activities. This is expected of all IIA organizations since they are the eyes and ears for the DOT.

Summary: The information above provides the reader a general outline of HSB's authority provided by DOT to provide RIN consulting and auditing activities. HSB's process has proven to be a successful path to Approval and/or renewal of DOT RIN Approvals. If there are any questions or inquiries in regard to the RIN topic please feel free to contact Bruce Redfield at bruce_redfield@hsb.com.

2021 Technical Training and Marketing Events

Dates	Loction	Topic
07/06 – 07/08	Virtual/US	2021 Code Synopsis
07/20 – 07/22	Virtual/US	ASME Sec VIII, Div 1
08/10 – 08/12	Virtual/US	2021 Code Synopsis
08/23 – 08/24	Virtual/US	ASME Sec I & B31.1
09/07 – 09/09	Virtual/Europe	2021 Code Synopsis
09/14 – 09/16	Virtual/US	ASME Section III
09/28 – 09/29	Virtual/Europe	ASME Section IX
10/05 – 10/07	Virtual/US	ASME Section V
11/09 – 11/11	Virtual/US	ASME Section IX & NBIC

For more information on HSB training and events, please email us at Getinfo@hsb.com

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